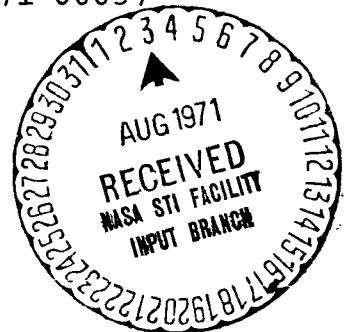




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PRE-PHASE A TUG STUDIES

(NASA-CR-119295)
(Bellcomm, Inc.) 46 p

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date: June 30, 1971

to: Distribution

from: A. S. Kiersarsky, H. S. London, D. Macchia

subject: Pre-Phase A Tug Studies - Case 105-4

MEMORANDUM FOR FILE

The Space Tug is a concept developed in NASA planning which would constitute a segment of a future space transportation system. Its ultimate role would be to support a complete spectrum of manned and unmanned missions such as manned lunar landings (as an advanced LM); movement of crew, cargo, and experiment modules between the Space Shuttle, a Space Station or Base, and a Translunar Shuttle; interorbital transfer of unmanned satellites; and injection of unmanned spacecraft on trans-planetary trajectories. Potential uses early in the Space Shuttle era (circa 1980) would be limited to delivery and retrieval of unmanned spacecraft, similar to the role envisioned by the Air Force for what they refer to as the Orbit-to-Orbit Shuttle (OOS).

Several Pre-Phase A studies to examine various tug concepts and to conduct preliminary tradeoffs have been completed. Contracted studies were carried out for NASA by North American Rockwell and the Boeing Company, and a study jointly sponsored by NASA and the Air Force was conducted by the Aerospace Corporation. In addition, two studies were carried out under contract to ELDO, the European Launcher Development Organization, by multi-national teams headed by Hawker Siddeley Dynamics (HSD) and Messerschmitt-Bolkow-Blohm (MBB) respectively. A working group has been established by NASA Headquarters to review the Pre-Phase A work, lay the groundwork for Phase A work statements, and identify requirements for related advanced studies and technology programs.

Representatives of NASA Headquarters, MSFC, MSC, ELDO, the Aerospace Corporation, and Bellcomm constitute the group. Bellcomm has reviewed the various approaches taken in the five Pre-Phase A studies, summarized significant results, and made a number of recommendations regarding future technical

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work in presentations at meetings of the working group during April, May, and June. The material presented at these meetings is summarized in the attachment in the form of viewgraphs with accompanying text. It is based primarily on review of the documents listed as references 1-7. Effort was concentrated on factors most strongly affecting performance and cost, rather than attempting to review all subsystems selections. The results and recommendations enumerated are not necessarily complete; furthermore they express the judgement and opinions of Bellcomm personnel and do not necessarily reflect the viewpoint of NASA or other participants in the working group.

It should be noted that the ELD0 teams are currently engaged in follow-on studies (still considered Pre-Phase A) which will be completed at the end of July 1971. It was not possible to encompass this follow-on work in our review activities, and it is recognized that some of the issues prompted by the earlier studies are currently being addressed.

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ASK
1013-HSL-ajj
DM

Enclosures
References
Attachments



REFERENCES

1. "Pre-Phase A Study for an Analysis of a Reusable Space Tug," Final Report, North American Rockwell, Space Division, NAS9-10925, March 1971.
2. "Pre-Phase A Technical Study for Use of SAT V, INT 21 and Other SAT V Derivatives to Determine an Optimum Fourth Stage," Final Report, Boeing Company, Aerospace Group, NAS8-5608, February 1971.
3. "General Design Considerations for the Chemical OOS Propulsion Stage," Aerospace Corp. Report TOR-0059 (6758-01)-15, December 31, 1970.
4. "Development Program, Schedule Technology, and Costs Orbit-to-Orbit Shuttle-Chemical," Aerospace Corp. Report TOR-0059(6758-01)-13, October 15, 1970.
5. "OOS Avionics," Aerospace Corp. Report TOR-0059(6758-01)-11, July 10, 1970.
6. "European Space Tug System Study," Pre-Phase A Study, Messerschmitt-Bolkow-Blohm GMBH, Space Division, UR-V-38(71), February 1971.
7. "European Space Tug," Pre-Phase A Study, Hawker Siddeley Dynamics Limited, HSD 7227, January 1971.
8. "Main Propulsion Selections; Pre-Phase A NASA Space Tug Studies," Bellcomm Memorandum for File by C. Bendersky, May 18, 1971.

TUG DEFINITION

REQUIRED SYSTEM CAPABILITIES

PLACEMENT AND RETRIEVAL

PAYOUT WEIGHT AND SIZE

EMPHASIS ON SPACE STATION SUPPORT, LOW EARTH
ORBIT SATELLITE, GEOSYNCHRONOUS, OR LUNAR MISSIONS

MANNED VS UNMANNED

SYSTEM OPERATION

SPACE VS GROUND BASED

MAJOR INTERFACES WITH SHUTTLE, PAYLOADS, AND TRANSLUNAR SHUTTLE

SINGLE VS MULTIPLE LAUNCHES (ON-ORBIT ASSEMBLY)

DEGREE OF AUTONOMY

SYSTEM DESCRIPTION

NUMBER AND SIZE OF STAGES

REUSABLE VS EXPENDABLE STAGES

CREW/CARGO MODULES

CONFIGURATION

SUBSYSTEMS

TUG DEFINITION

THE SIGNIFICANT VARIABLES REQUIRED FOR DEFINITION OF THE SPACE TUG ARE LISTED HERE AND ARE CATEGORIZED INTO SYSTEM CAPABILITIES, SYSTEM OPERATION, AND SYSTEM DESCRIPTION. NOTEWORTHY IS A MARKED DIFFERENCE IN TREATMENT OF MANY OF THE ITEMS IN THE EUROPEAN AND AMERICAN TUG STUDIES, RANGING FROM DETAILED ANALYSES AND TRADEOFFS TO ARBITRARY ASSUMPTIONS . NO SINGLE CONTRACTOR CONSIDERED ALL ITEMS BUT THE SUM TOTAL OF THE TUG STUDIES PROVIDE DATA, CONCLUSIONS, OR INSIGHT IN EACH AREA SUITABLE FOR DEFINITION OF FUTURE STUDY WORK. THIS TUG STUDY WORK WILL BE SUMMARIZED IN THE FOLLOWING CHARTS.

GROUND RULES

CONTRACTOR	MISSIONS	PAYOUT	TUG LIFE	NUMBER OF REUSES	BASING	EOS CAPABILITY	EOS BAY SIZE	EOS COST/FLT.
HSD	<ul style="list-style-type: none"> Primary Mission. Geo-synch. To Geo-synch. Other Missions Cons. 	<ul style="list-style-type: none"> 4400#-13200# To Geo-synch. At least 3 years. 	<ul style="list-style-type: none"> At least 20 times. 	<ul style="list-style-type: none"> Earth based. 	<ul style="list-style-type: none"> • 47000# To 28°. 100 n.m/ 28°. 	<ul style="list-style-type: none"> • 15 ft. Dia x 60 ft. 1g. 	<ul style="list-style-type: none"> • \$4.5 x 10⁶ 	
MBB	<ul style="list-style-type: none"> Primary Mission Geo-synch. To Geo-synch. Other Missions Cons. 	<ul style="list-style-type: none"> 4400#-13200# To Geo-synch. At least 3 years. 	<ul style="list-style-type: none"> Expend. 1/2 yr. Reusable Grnd based 1 yr. Space Based 3yr. 	<ul style="list-style-type: none"> • SYN-12 • LEO-30 • Space based 	<ul style="list-style-type: none"> • Earth based • Space based 	<ul style="list-style-type: none"> • 47000# To 28°. 100 n.m/ 28°. 	<ul style="list-style-type: none"> • 15 ft. Dia x 60 ft. 1g. 	<ul style="list-style-type: none"> • \$4.5 x 10⁶
NAR	<ul style="list-style-type: none"> Earth Orb. Geo-synch. To Geo-synch. Lunar Plane-tary. 	<ul style="list-style-type: none"> 10,000# To Geo-synch. Up to 3 yrs. 	<ul style="list-style-type: none"> SYN-10 • Primary • Earth based also Cons. 	<ul style="list-style-type: none"> • LEO-50 • Space based. 	<ul style="list-style-type: none"> • 45000# To 28°. 100 n.m/ 28°. 	<ul style="list-style-type: none"> • 15 ft. Dia x 60 ft. 1g. 	<ul style="list-style-type: none"> • 4.5 x 10⁶ 	
BOEING	<ul style="list-style-type: none"> Earth Orb. Geo-synch. To Geo-synch. Lunar Plane-tary. 	<ul style="list-style-type: none"> 10,000# To Geo-synch. Not de-fined. 	<ul style="list-style-type: none"> SYN-20 LUN-10 INT-NONE 	<ul style="list-style-type: none"> • LEO-50 • Space based. 	<ul style="list-style-type: none"> • Up to 54000# To 28°. 100 n.m/ 28°. 	<ul style="list-style-type: none"> • 15 ft. Dia x 60 ft. 1g. 	<ul style="list-style-type: none"> • 3.5 x 10⁶ 	
AEROSPACE	<ul style="list-style-type: none"> Earth Orb. Geo-synch. To Geo-synch. Lunar Plane-tary. 	<ul style="list-style-type: none"> 11,000# To Geo-synch. 1 Year For Space based. 	<ul style="list-style-type: none"> ----- 	<ul style="list-style-type: none"> • Space based. • Earth based. 	<ul style="list-style-type: none"> • 80,000# To 28.5°. 100 n.m/ 28.5°. 	<ul style="list-style-type: none"> • 15 ft. Dia x 60 ft. 1g. 	<ul style="list-style-type: none"> ----- 	

GROUND RULES

DIFFERENCES IN GROUND RULES USED IN THE TUG STUDIES ARE ILLUSTRATED HERE. THESE GROUND RULES ARE A RESULT OF NASA OR ELD0 INPUTS, OR DECISIONS MADE BY THE STUDY CONTRACTORS.

EUROPEAN STUDY EMPHASIS AND STAGE DESIGN WAS BASED ON THE GEOSYNCHRONOUS MISSION WHEREAS THE AMERICAN CONTRACTORS CONSIDERED LOW EARTH ORBIT, LUNAR, AND PLANETARY MISSIONS AS WELL. THE GEOSYNCHRONOUS MISSION ESSENTIALLY SIZES ALL STAGES, BUT MAJOR DIFFERENCES IN STAGE SIZE WOULD RESULT FROM DIFFERENT ASSUMED PAYLOAD REQUIREMENTS. THE AMERICANS SIZED THE TUG FOR 10,000 LB GEOSYNCHRONOUS DELIVERY WITH A REUSABLE OR PARTIALLY REUSABLE SYSTEM. THE EUROPEANS CONSIDERED A RANGE OF 4400-13,200 LBS PAYLOAD WITH THE RESTRICTION OF A SINGLE SHUTTLE LAUNCH. LEADING TO AN EXPENDABLE TUG FOR THE HIGH END OF THE RANGE.

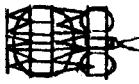
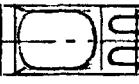
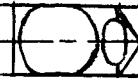
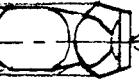
TUG LIFE AND REUSABILITY GROUND RULES RESULT FROM REITERATION OF ELD0 AND NASA INPUTS AND SOME CONTRACTOR ASSUMPTIONS. THERE ARE NO SUPPORTING ANALYSES. THESE DIFFERENCES APPEAR TO AFFECT TOTAL PROGRAM COSTS ONLY (FOR ASSUMED MISSION MODELS) RATHER THAN STAGE DESIGN. SIMILARLY THE EOS FLIGHT COST AFFECTS PROGRAM COST ONLY. IN THIS AREA BOEING CONSIDERED A RANGE OF EOS COSTS SURROUNDING THEIR SELECTED COST.

REGARDING BASING, THE EUROPEANS ELECTED TO TAKE A MORE CONSERVATIVE APPROACH AND GROUND RULED EARTH BASING FOR THEIR TUGS. BOEING AND AEROSPACE CONSIDERED BOTH GROUND AND SPACE BASING BUT NAR WAS INSTRUCTED TO GROUND RULE SPACE BASING.

(SPACE BASING HAS OPERATIONAL ADVANTAGES FOR HIGH LEVELS OF ACTIVITY SINCE IT PERMITS A LARGER TUG STAGE AND CORRESPONDINGLY HIGHER PAYLOADS, AND FREES MORE EOS CARGO SPACE AND WEIGHT FOR PAYLOAD AND FUEL, ULTIMATELY REDUCING THE NUMBER OF EOS FLIGHTS FOR A GIVEN MISSION MODEL.)

NOTEWORTHY IS THE WIDE VARIATION IN ASSUMED EOS PAYLOAD CAPABILITY. THE VALUES ASSUMED BY THE EUROPEANS, NAR, AND BOEING CAME FROM NASA AND REFLECT SHUTTLE CONTRACTORS' RESULTS AT DIFFERENT POINTS IN TIME. AEROSPACE WAS WORKING TO EARLIER SHUTTLE REQUIREMENTS. THE ASSUMED EOS CAPABILITY FOR ALL EXCEPT THE AEROSPACE STUDY WAS LESS THAN THAT CURRENTLY SPECIFIED IN THE PHASE B SHUTTLE STUDIES.

CONFIGURATION COMPARISON

CONTRACTOR	CONFIGURATION	TANKAGE ARRANGEMENT	TANKAGE MATERIAL	TANKAGE INSULATION	METEOROID PROTECTION	DOCKING
HSD		1 LH ₂ Tank 4 LO ₂ Tanks	Alum. (2021)	Closed cell Foam substrate & H.P.I.	Honeycomb Panels - Nonstructural	Menasco type system
MBB		1 LH ₂ Tank 4 LO ₂ Tanks	Alum. (2021)	Closed cell Foam substrate & H.P.I.	H.P.I. Outer Jacket used as bumper	Menasco type system
NAR		1 LH ₂ Tank 4 LO ₂ Tanks	Alum.	H.P.I.	H.P.I. Outer Jacket used as bumper	Apollo probe and drogue type
BOEING		1 LH ₂ Tank 1 LO ₂ Tank	Alum. (2219)	H.P.I.	Honeycomb Panel Alum faces with Hexcel core	Docking adapter kit
AEROSPACE		1 LH ₂ Tank 1 LO ₂ Tank	Alum. (2021)	H.P.I.	Double walled panel Alum faces with open cell foam filler	Aft mounted docking collar

CONFIGURATION COMPARISON

THE BASELINE CONFIGURATIONS SELECTED BY THE CONTRACTORS ARE COMPARED IN THE ADJOINING MATRIX. IN THESE STUDIES THE TUG WAS SUPPORTED EITHER WITHIN THE SPACE SHUTTLE PAYLOAD BAY OR WITHIN A SHROUD WHEN LAUNCHED BY THE SATURN V. EITHER OF THESE SUPPORT METHODS PROVIDES A RELATIVELY BENIGN ENVIRONMENT FOR THE TUG BY ELIMINATING SOME OF THE CRITICAL DESIGN CONDITIONS SUCH AS WIND LOADING, ASCENT HEATING, AND OTHER AERODYNAMIC EFFECTS ASSOCIATED WITH CONVENTIONAL BOOSTERS.

THERE WERE TWO BASIC DESIGN APPROACHES: (1) THE SPACE FRAME (TRUSS TYPE) DESIGN SELECTED BY THE ELD0 CONTRACTORS AND AEROSPACE, AND (2) THE SKIN STRINGER DESIGN SELECTED BY NAR AND BOEING. PROPELLANT TANKAGE ARRANGEMENTS CONSISTED OF A SINGLE LH₂ TANK FOR ALL DESIGNS WITH SINGLE OR MULTIPLE LO₂ TANKS. THE PRIMARY DRIVER FOR MULTIPLE LO₂ TANKS BY THE ELD0 CONTRACTORS WAS TO MINIMIZE STAGE LENGTH. NAR SELECTED MULTIPLE LO₂ TANKS BECAUSE OF MULTIPLE ENGINE ATTACHMENT CONSIDERATIONS.

THE SELECTED TANKAGE MATERIALS HAVE BEEN PREVIOUSLY USED AND HAVE WELL DEFINED STRUCTURAL AND PROPELLANT COMPATIBILITY CHARACTERISTICS, AND ESTABLISHED FABRICATION TECHNIQUES. INSULATION FOR THE PROPELLANT TANKAGE WAS HIGH PERFORMANCE INSULATION (H.P.I.) WHICH CONSISTS OF MULTILAYERED ALUMINUM COATED MYLAR. ALONG WITH HPI, THE ELD0 CONTRACTORS USED A CLOSED CELL-FOAM SUBSTRATE.

THE METEOROID PROTECTION DESIGN APPROACH WAS BASICALLY THE SAME--A SEPARATE OUTER SHELL OF VARIOUS TYPES OF CONSTRUCTION. IN ONE DESIGN (MBB), THE HPI SUPPORT JACKET WAS CONSIDERED ADEQUATE. BOTH OF THE ELD0 CONTRACTORS DID INDICATE HOWEVER THAT THEIR PREVIOUS BACKGROUND IN METEOROID PROTECTION WAS LIMITED.

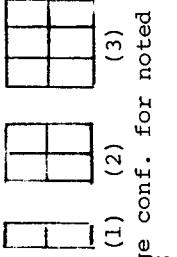
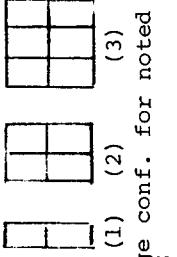
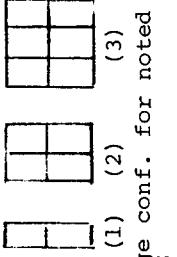
THE DOCKING SYSTEMS ARE IDENTIFIED HERE AND WILL BE DISCUSSED FURTHER AS PART OF THE REVIEW OF DOCKING CONCEPTS.

REUSABLE CONFIGURATIONS FOR GEO-SYNCH

VERSION	BASESTAGE	TANDEM REUSABLE	SINGLE STAGE REUSABLE	TANDEM REUSABLE	SINGLE STAGE REUSABLE	TANDEM REUSABLE	BASESTAGE	TANDEM REUSABLE	AEROSPACE	
									NAR	BOEING
L	21100#	42240#	38200#	*	89000#	101,000	47800#	95300	69,000	
(NO P/L)										
PROP (USABLE)	17500#	EA. 17500 ST.	33000#	*	78000#	41,000 EA. ST.	39800*	39800 EA. ST.	61,000	
DRY WT.	3360#	EA. 3360 ST.	3780#		11075	9065 EA. ST.	8000#	8000 1st 8140 2nd	6,380	
λ	.826		.866		.873	.810	.832		.884	
ENGINE THRUST	(1) 11,000# (1) 11,000 EA. ST.	(1) 11,000	(1) 11,000	(4) 9000	(4) 9000	(4)	EA.	(1) 23300# (1) 23300 EA. ST.	23,800	
I _{sp}	450 SEC	460 SEC	460 SEC	463 SEC	463 SEC	463 SEC	460 SEC	460 SEC	460 SEC	460 SEC
DELIVERED P/L	Δ	4630#*	4630	16000#	10,000	10,000	Δ	(1) 10,000	11,000	
RETRIEVABLE P/L	Δ	1560#	1890#	7925#	3900	3900	Δ	(2)>10,000		
ROUNDTRIP P/L	Δ	1170#	1340#	5640#			Δ	(3)>10,000		

*VARIES DEPENDING ON MISSION.

Δ -NOT DEFINED
 *Delta Payload
 = +400 lbs for I_{sp} = 460



(1) (2) (3)
 Stage conf. for noted P/Ls

SPACE TUG SIZES FOR GEOSYNCHRONOUS MISSIONS

THE FOLLOWING CHART SHOWS THE BASELINE CONFIGURATIONS FOR A REUSABLE GEOSYNCHRONOUS MISSION TUG. THE EUROPEAN TUGS WERE SIZED FOR A SINGLE LAUNCH OF A SHUTTLE WITH 47K PAYLOAD, RESULTING IN MUCH SMALLER TUG PAYLOAD THAN THE AMERICAN CONCEPTS WHICH ASSUMED EITHER SPACE BASING, MULTIPLE SHUTTLE LAUNCHES, OR A LARGER SHUTTLE TO ACHIEVE 10K TO GEOSYNCHRONOUS ORBIT. EXPENDABLE VERSIONS OF ELD0 DESIGNS ARE USED TO DELIVER 10K CLASS PAYLOADS. THE EUROPEAN TUGS, EXCEPT FOR MBB IN A DUAL LAUNCH TANDEM CONFIGURATION, HAVE PAYLOAD RETRIEVAL CAPABILITY OF LESS THAN ONE TON AND THIS MAY COMPROMISE THEIR UTILITY. NONE OF THE TUG CONCEPTS CAN RETRIEVE A 10,000 LB PAYLOAD: THIS REQUIRES MULTIPLE LAUNCHES AND A COMPLEX STAGING MODE SUGGESTED BY BOEING.

REGARDING SPECIFIC NUMBERS ON THE CHARTS IT IS NOTED THAT AVIONICS WEIGHTS ARE INCLUDED IN THE STAGE DRY WEIGHTS. THE TOTAL INERT WEIGHTS, USED IN COMPUTING STAGE MASS FRACTIONS (λ), INCLUDE RESIDUALS AND ACS PROPELLANTS IN ADDITION TO STAGE DRY WEIGHT. STAGE THRUST TO WEIGHT RATIO RANGES FROM .24 TO .41.

EXPENDABLE OR PARTIALLY EXPENDABLE CONFIGURATIONS
(GEO-SYNCH)

Version	Single Stage Expendable	Single Stage Expendable	Reusable Plus Kickstage Exp.	1 1/2 Stage	15D	Tank Set Expendable	NAR		Burner II or Taros	MBB	HSD	27.4	26.4	13.75D	13.75D	Tank Set
							Reusable	Kickstage								
LAUNCH WT. (NO P/L)	33400#	38000#	39860													85000#
PROP (USABLE)	29700#	33000#														11000# (MINI STAGE) 52000# (Tank Set)
DRY WT.	3720#	3820#														6735 4915
λ	.889	.87														.604/.917
ENGINE THRUST	(1) 17,600#	(1) 11,000#														(4) 7000#
I _{SP}	450 SEC	450 SEC														463 SEC
DELIVERED P/I	13400#	12950#	7000#													10,000#
																SIMILAR TO REUSABLE REUSABLE STAGE 'B', STAGE SAME AS STAGE 'B'

EXPENDABLE AND PARTIALLY EXPENDABLE CONFIGURATIONS

THIS CHART SHOWS EXPENDABLE VERSIONS OF THE HSD AND MBB TUGS. NOTE THAT APPROXIMATELY 13,000 LB CAN BE DELIVERED TO GEOSYNCHRONOUS ORBIT.

ALSO SHOWN FOR INTEREST IS A NAR PARTIALLY EXPENDABLE CONCEPT CONSISTING OF A SMALL REUSABLE TUG DESIGNED FOR LOW ALTITUDE SUPPORT MISSIONS PLUS AN EXPENDABLE TANK SET, WHICH WAS ONE OF ELEVEN CONCEPTS THEY STUDIED. NOTE - WORTHY IS THAT THE LAUNCH WEIGHT IS WELL OVER TWICE THE EUROPEAN EXPENDABLE TUG WEIGHTS, AND THE PAYLOAD IS LESS. CONSIDERING THE COMPLICATIONS ARISING FROM STAGING THE TANK SET, THE TANK SET COST, AND THE EXTRA SHUTTLE FLIGHT REQUIRED TO PERFORM THE MISSION, IT IS DEBATABLE WHETHER THE 1 1/2 STAGE CONCEPT IS Viable FOR A PROGRAM WEIGHTED TOWARDS GEOSYNCHRONOUS MISSIONS.

USE OF THE BASELINE REUSABLE TUG WITH A SMALL EXPENDABLE SOLID PROPELLANT KICK-STAGE, AS IN THE MBB CONCEPT, APPEARS TO BE A MORE EFFICIENT METHOD TO LAUNCH LARGE PAYLOADS TO GEOSYNCHRONOUS ORBIT. THIS CONCLUSION IS REINFORCED BY NAR DATA WHICH INDICATE THAT A FULL SCALE REUSABLE TUG, SIZED FOR THE GEOSYNCHRONOUS MISSION, OPERATED WITH PROPELLANT OFFLOADED IS NEARLY AS EFFICIENT AS A SMALL TUG FOR LOW-ALTITUDE MISSIONS.

MISSION MODELS

CONTRACTOR	LEO UNMANNED	LEO MANNED	EARTH MANNED	GEO-- SYNCH	SPACE STATION	LUNAR	PLANE- TARY	SPACE- CRAFT MAINT.	TOTAL MISSIONS
HSD (10 YEAR BASE)									217
MBB (15 YEAR BASE)									
PLAN A	35	160	230	20	35	480			
PLAN B	25	92	100	11	22	250			
PLAN C	25	94	-	11	22	152			
NAR (10 YEAR BASE)									1852
BOEING (10 YEAR BASE)	142	340	287	60	35	864			

MISSION MODELS

IT IS APPARENT FROM THIS CHART THAT THE TUG STUDY CONTRACTORS WORKED TO VASTLY DIFFERENT MISSION MODELS... IN TERMS OF TOTAL MISSIONS AND PERCENTAGE OF FLIGHTS ALLOCATED TO EACH MISSION AREA. THESE MODELS APPEAR TO BE USED PRINCIPALLY FOR DETERMINING TOTAL PROGRAM COST. IT IS NOT CLEAR WHAT IF ANY IMPACT ASSUMED MISSION MODELS HAVE ON CONFIGURATION, SUBSYSTEMS SELECTION, AND PREFERRED OPERATIONAL MODES. (THIS IS PARTICULARLY TRUE OF THE NAR MODEL WHICH AVERAGES 185 FLIGHTS/YEAR.)

MISSION MODEL IMPACT SHOULD BE IDENTIFIED BY THE TUG CONTRACTORS. HOWEVER, IN ALL CASES THE GEOSYNCHRONOUS MISSION REQUIREMENT SIZES THE CONTRACTOR BASE-LINE STAGE (OR STAGES FOR TANDEM STAGING). OTHER MISSION AREAS USE THE BASELINE STAGE WITH APPROPRIATE MODIFICATIONS OR ADDITIONAL MODULES.

COST SUMMARY (A)

	DEVELOPMENT COST	UNIT COST	GEOSYNCH MISSION COST
HSD	<ul style="list-style-type: none"> • REUSABLE \$531 MIL • EXPENDABLE \$472 MIL 	<ul style="list-style-type: none"> • REUSABLE \$14.2 MIL • EXPENDABLE \$10.9 MIL 	<ul style="list-style-type: none"> • REUSABLE COST 1.979 • EXPENDABLE COST 1.982 <p>• REUSABLE \$5.2 MIL + UNIT COST AMORT. • EXPENDABLE \$5.0 MIL + UNIT COST (10.9) • SMALL MISSION COST IMPROVEMENT BEYOND 30 REUSES - 10 TO 20 REUSES SUGGESTED</p>
MBB	<ul style="list-style-type: none"> • SINGLE TUG CONCEPT \$355 MIL 	<ul style="list-style-type: none"> • REUSABLE \$11.3 MIL • EXPENDABLE \$9.0 MIL 	<ul style="list-style-type: none"> • TOTAL PROGRAM SIZE DEPENDENT \$6.3-7.1 MIL AVG. COST
NAR	<ul style="list-style-type: none"> • UNMANNED E.O. \$560 MIL • MANNED E.O. \$390 MIL* • LUNAR \$520 MIL* (ADDED TO PRIOR DEVELOPMENTS) 	<ul style="list-style-type: none"> • PROPULSION MODULE \$8.9-13.2 MIL • INTELLIGENCE MODULE \$38.3-39.7 MIL • TANK SET (CONCEPT 11) \$6.7 MIL • CREW MODULE \$18.8 MIL 	<ul style="list-style-type: none"> • SPACE BASED \$16.2 MIL \$11.1 MIL WITH OMS SHARING
BOEING	<ul style="list-style-type: none"> • UNMANNED PM & AM > \$500 MIL • MANNED PM, AM, CM ~\$1,000 MIL • CARGO MOD. & KITS ~\$1,200 MIL 	<ul style="list-style-type: none"> • UNMANNED ~\$16 MIL • MANNED ~\$45 MIL 	<ul style="list-style-type: none"> • SPACE BASED: TANDEM STAGED \$9.9 MIL • RECURRING COSTS VERY SENSITIVE TO REUSE RATE, REFURBISHMENT COST, SHUTTLE FLIGHT COST - OVER 50 REUSES DESIRABLE - REFURB. < 3% DESIRABLE
AEROSPACE	<ul style="list-style-type: none"> • HIGH PERFORMANCE STAGE \$448 MIL 	<ul style="list-style-type: none"> • \$13.1 MIL 	<ul style="list-style-type: none"> • FLIGHT RATE AND REUSE CAPABILITY DEPENDENT

COST SUMMARY (A)

TO BE NOTED HERE ARE THE COMPARABLE DEVELOPMENT COST ESTIMATES FOR A GEO-SYNCHRONOUS MISSION TUG... ABOUT \$.5 BILLION FOR AN UNMANNED TUG AND \$1 BILLION FOR A MANNED VERSION. UNIT COSTS FOR A RESUABLE TUG ARE ALSO SIMILAR EXCEPT FOR NAR WHICH HAS A SINGULARLY HIGH INTELLIGENCE MODULE COST. (FOR PRESUMABLY SIMILAR CAPABILITY NAR ESTIMATES \$52.9 MILLION TOTAL TUG FIRST UNIT COST VS. \$13.1 AND \$16 MILLION BY AEROSPACE AND BOEING.)

MISSION COSTS RANGE FROM \$6 TO \$16 MILLION WITH THE EUROPEAN ESTIMATES ON THE LOW END OF THIS RANGE. TWO SHUTTLE LAUNCHES ARE REQUIRED PER MISSION FOR THE NAR AND BOEING TUGS, WHICH ACCOUNTS FOR PART OF THE DIFFERENCES. REGARDING THESE COSTS, NAR POINTS OUT THAT SIGNIFICANT SAVINGS ARE POSSIBLE VIA SHUTTLE ORBITAL MANEUVERING SYSTEM (OMS) PROPELLANT SHARING WITH THE TUG. THE MAGNITUDE OF THE SAVINGS (\$11.2 VS 16.2 MIL) SUGGESTS THAT THIS BE STUDIED FURTHER TO ESTABLISH FEASIBILITY. MISSION COST IS SENSITIVE TO THE REUSE CAPABILITY OF THE TUG WHICH HAS BEEN ASSUMED TO BE FROM 10 TO 20 REUSES FOR SYNCHRONOUS ORBIT MISSIONS. BECAUSE OF THIS SENSITIVITY A THOROUGH ANALYSIS OF REUSE CAPABILITY IS REQUIRED.

COST SUMMARY (B)

	EFFECT OF CONCEPT SELECTION	EFFECT OF OPERATIONAL MODE
HSD	<ul style="list-style-type: none"> • REUSABLE TUG SUPERIOR TO EXPENDABLE CONSIDERING FLEXIBILITY AS WELL AS COST • REUSABLE TUG VS CONVENTIONAL L.V. GEOSYNCH PROG. COST BREAKEVEN POINT DEPENDENT ON INFLATION FACTOR <ul style="list-style-type: none"> - INCLUSION OF SAT. COST INCREASES ADVANTAGE OF REUSABLE VEHICLE - LAUNCH COSTS COMPARABLE - RAPID COST INCREASE FOR < .82 FOR TWO STAGE REUSABLE 	<ul style="list-style-type: none"> • GEOSYNCH TANK FARM MAY BE JUSTIFIABLE FOR PAYLOAD ROUNDTRIP & RECOVERY MISSIONS <ul style="list-style-type: none"> - LITTLE VALUE IN PLACEMENT
MBB	<ul style="list-style-type: none"> • TRANSPORTATION COST TO GEOSYNCH CAN BE REDUCED TO ~ 1/3 OF PRESENT EXPENDABLE L.V. COST (TITAN CLASS) <ul style="list-style-type: none"> - SPACE TUG DEVELOPMENT COST AMORTIZATION AT ~ 22 MISSIONS 	<ul style="list-style-type: none"> • IN ORBIT SATELLITE REPAIR & RETRIEVAL MAY ALLOW \$50-150 MIL <u>ANNUAL</u> SAVINGS
NAR	<ul style="list-style-type: none"> • NEGLIGIBLE DIFFERENCES IN 10 YR TOTAL PROGRAM COST FOR 3 CONCEPTS (SPACED BASED) • COMPARABLE OR CHEAPER 10 YR GEOSYNCH PROGRAM COST FOR RE-USABLE TUG VS EXPENDABLE 	<ul style="list-style-type: none"> • MINOR MISSION COST DIFFERENCES WITH DEGREE OF AUTONOMY • SATELLITE RETRIEVAL SAVINGS ESTIMATED AT \$240 MIL <u>OVER 10 YEARS</u>
BOEING	<ul style="list-style-type: none"> • AEROBAKED GEOSYNCH MISSIONS SUGGESTED ON BASIS OF PERFORMANCE <ul style="list-style-type: none"> - NO COST ESTIMATE BUT MUCH SMALLER TUG RESULTS • EARLY BREAKEVEN (~ 25 MISSIONS) ON REUSABLE TUG VS TITAN/CENTAUR 	<ul style="list-style-type: none"> • SPACED BASED VS GROUND BASED UNRESOLVED

COST SUMMARY (B)

COST CONCLUSIONS PERTAINING TO CONCEPT SELECTION AND OPERATIONAL MODE ARE SUMMARIZED HERE. THE CONTRACTORS DEMONSTRATED THAT THE REUSABLE TUG CAN BE CHEAPER THAN AN EXPENDABLE TUG OR CONVENTIONAL LAUNCH VEHICLES. THE BREAK-EVEN POINT (WHICH CONSIDERS DEVELOPMENT AS WELL AS OPERATIONAL COSTS) IS IN QUESTION AND THIS POINT IS SENSITIVE TO SHUTTLE LAUNCH COSTS, TUG USE COSTS, INFLATION FACTORS, MISSION MODEL, ETC. ADDITIONAL SAVINGS OVER AND ABOVE LAUNCH COSTS ACCRUE FROM SATELLITE REPAIR AND RETRIEVAL BUT THE EXTENT OF SUCH SAVINGS IS NOT CLEAR AS EVIDENCED BY THE DIFFERENT ESTIMATES OF MBB AND NAR.

OTHER SIGNIFICANT CONCLUSIONS BY NAR ARE THAT CONCEPT SELECTION HAS NEGLIGIBLE IMPACT ON TOTAL PROGRAM COST, AND DEGREE OF AUTONOMY DOES NOT MARKEDLY AFFECT MISSION COST. THESE CONCLUSIONS WERE BASED ON ANALYSIS OF THREE CONCEPTS (SINGLE STAGE, TANDEM STAGE, 1 1/2 STAGE) AND THREE LEVELS OF AUTONOMY.

THE VARIOUS CONTRACTORS ASSUMED (OR WERE DIRECTED IN THE CASE OF NAR) DIFFERENT BASING CONCEPTS FOR REASONS NOT RELATED TO COST. BOEING CONCLUDES THAT, FROM A COST POINT OF VIEW, THE SPACE VS GROUND BASED ISSUE IS UNRESOLVED.

CONTRACTOR COMMENTS ON AEROBRAKING AND TANK FARMS ARE NOTED IN THE CHART AND THESE SHOULD BE VIEWED AS PRELIMINARY DUE TO THE NATURE OF THE ANALYSIS.

SUPPORT SYSTEMS COMPARISON
INTEGRAL VS MODULAR

	HSD	INTEGRAL	AEROSPACE (HIGH. PERF.)	NAR	MODULAR	BOEING
EPS	400	275	470	500		
DATA MAN.	78	60	110	101		
COMM.	36		630	935		
GUID. & CONTROL	179	143	276			
ACS (LESS PROP.)	55	141	358	NOT INCLUDED		
STRUCT. (MOD)	---	---	520			
			1590	2690	1890-3115	
		748	619			
					<ul style="list-style-type: none"> • TOTALY INTEG. IM COMPONENTS -400 • MODULAR AVIONICS ONLY -200 • GRND BASED MED. AUTONOMY -1050 	<ul style="list-style-type: none"> • ACS WGT. +480

INTEGRAL VS MODULAR SUPPORT SYSTEMS

AVIONICS AND OTHER SUPPORT SYSTEMS WEIGHTS ARE COMPARED HERE. THE RANGE OF WEIGHTS REFLECT DIFFERENCES IN THE DEGREE OF AUTONOMY, MODULAR VS INTEGRAL SYSTEMS, SPACE VS GROUND BASING, AND SYSTEMS CAPABILITIES. THESE DIFFERENCES ARE NOT FULLY RESOLVED AT THIS TIME.

BOTH THE BOEING AND NAR DESIGNS APPEAR TO PAY A SIGNIFICANT STRUCTURAL WEIGHT PENALTY FOR A DETACHABLE AVIONICS MODULE, ESTIMATED AT ABOUT 400 LBS FOR THE NAR DESIGN. WE ESTIMATE THAT THE BOEING CONCEPT INCURS AN ADDITIONAL PENALTY FOR MODULARIZATION OF ABOUT 400 LBS RESULTING FROM THERMAL CONTROL REQUIREMENTS. NAR USES A COMMON MODULE FOR GEOSYNCHRONOUS, LUNAR, PLANETARY, AND LOW EARTH ORBIT MISSIONS AND BOEING USES SEPARATE MODULES FOR EACH MISSION AREA. LARGER WEIGHT DIFFERENCES BETWEEN THE VARIOUS CONCEPTS ALSO ARISE FROM THE OPERATIONS REQUIRED OF THE TUG. FOR EXAMPLE NAR ESTIMATES THAT CHANGING FROM SPACE BASED, MAXIMUM AUTONOMY TO GROUND BASED, MEDIUM AUTONOMY SAVES OVER 1000 LB INERT WEIGHT. (NAR AVIONICS WOULD THEN BE ROUGHLY COMPARABLE TO AEROSPACE.)

EUROPEAN AVIONICS ARE LOW IN WEIGHT; THIS IS PROBABLY CONSISTENT WITH THEIR ASSUMED OPERATIONAL MODES AND SYSTEMS WHICH ARE SIMPLER, REQUIRE LESS REDUNDANCY, ETC. BY WAY OF ILLUSTRATION COMPUTER STORAGE CAPABILITY IN THE EUROPEAN AVIONICS IS ~8K TO 12K WORDS VS 250K FOR NAR WHICH IMPLIES FAR LESS AUTONOMOUS OPERATION CAPABILITY.

MAIN PROPULSION CONSIDERATIONS

- OPTIMUM THRUST/WEIGHT $\sim .2-.3$ FOR REUSABLE GEOSYNCHRONOUS MISSION
- OPTIMUM THRUST $\sim 9000-30,000$ LBS DEPENDING ON GROSS WEIGHT
- RL-10-8 PRACTICALLY A NEW ENGINE
PUMPS, TURBINES, CONTROLS, DRIVES
NEW CHAMBER MAY BE REQUIRED FOR MR = 6
- CRYOROCKET ENGINE CONCEPT - HEAVY TOTAL SYSTEM WEIGHT
SINGLE SHAFT TURBOPUMP
GASEOUS FLUORINE IGNITION
BOOST PUMPS OR HIGH PROPELLANT TANK PRESSURE
$$\frac{\Delta W_{PL}}{\Delta W_{BO}} \sim -4$$
 LBS/LB FOR GEOSYNCHRONOUS PLACEMENT
- AF SPONSORING OOS ENGINE STUDIES
NEW HIGH PC ENGINE, 8K-50K LBS THRUST
- POSSIBLE COMMONALITY WITH SHUTTLE OMS

MAIN PROPULSION CONSIDERATIONS

TRADEOFFS OF GRAVITY LOSS VS ENGINE WEIGHT CONDUCTED IN THE STUDIES INDICATE THAT THE RATIO OF THRUST TO GROSS WEIGHT IN LOW ALTITUDE ORBIT SHOULD BE IN THE RANGE OF 0.2-0.3 FOR MAXIMUM PAYLOAD ON GEOSYNCHRONOUS MISSIONS. THEREFORE THE OPTIMUM THRUST LEVEL CAN BE ANYWHERE IN THE RANGE OF 9000-30,000 LBS DEPENDING ON TUG GROSS WEIGHT.

BOEING AND AEROSPACE BOTH CHOSE THE RL-10-8, AN ADVANCED VERSION OF THE CURRENT PRATT AND WHITNEY RL-10, WHICH AT APPROXIMATELY 23,000 LBS THRUST IS APPROPRIATE FOR THEIR BASELINE TUGS OF ABOUT 100,000 AND 80,000 LBS GROSS WEIGHT (PAYLOAD INCLUDED) RESPECTIVELY. IT SHOULD BE RECOGNIZED, HOWEVER, THAT THIS ENGINE REPRESENTS PRACTICALLY A COMPLETE NEW DEVELOPMENT; NEW PUMPS, TURBINES, CONTROLS AND DRIVES ARE INCORPORATED TO ACHIEVE HIGHER CHAMBER PRESSURE, LOW SUCTION PRESSURE OPERATION, THROTTLING CAPABILITY, QUICK CHILDDOWN, AND MULTIPLE RESTART CAPABILITIES. FURTHERMORE, A NEW THRUST CHAMBER MAY BE REQUIRED IF OPERATION AT AN OXIDIZER/FUEL RATIO OF 6 IS REQUIRED (THE EUROPEAN VEHICLE TRADEOFFS INDICATE THAT THE OPTIMUM O/F IS APPROXIMATELY 6).

THE EUROPEAN REUSABLE TUG BASELINE CONCEPTS BOTH UTILIZE AN 11,000 LB THRUST CRYOROCKET ENGINE CONCEPT, WHICH IS NEAR OPTIMUM THRUST FOR THEIR GROSS WEIGHT OF 47,000 LBS. THE PREDICTED THRUST-TO-ENGINE SYSTEM WEIGHT RATIO IS ONLY AROUND 30, COMPARED TO AROUND 50 FOR THE RL-10 FAMILY AND AS HIGH AS ABOUT 70 FOR A NEW 30,000 LB THRUST ENGINE (NAR ESTIMATE). THIS IS DUE AT LEAST IN PART TO THE CHARACTERISTICS OF ENGINE COMPONENTS SELECTED. PARTICULARLY, THE USE OF A GASEOUS FLUORINE SLUG FOR ENGINE START IS HEAVY COMPARED WITH SPARK IGNITION, AND ALSO INTRODUCES OPERATIONAL COMPLEXITY, POTENTIAL CONTAMINATION, AND A LIMIT ON THE NUMBER OF RESTARTS. THE HSD TUG DESIGN ALSO UTILIZES BOOST PUMPS WHICH INTRODUCE ADDITIONAL WEIGHT AND OPERATIONAL COMPLEXITY

TO THE ENGINE SYSTEM. ALTHOUGH THEY PERMIT LIGHTER PROPELLANT TANKS AND PRESSURIZATION SYSTEM, HSD'S ANALYSIS OF THE USE OF BOOST PUMPS WHICH INDICATES AN 880 LB (19 PERCENT) PAYLOAD INCREASE MUST BE REGARDED WITH SKEPTICISM AT THIS POINT.* AT ANY RATE, IT APPEARS THAT A SUBSTANTIAL WEIGHT PENALTY IS BEING INCURRED FOR NOT USING MORE UP-TO-DATE SYSTEM TECHNOLOGY. THIS MAY BE IMPORTANT FOR THE TUG, SINCE FOR THE GEOSYNCHRONOUS PAYLOAD DELIVERY MISSION, THE TRADEOFF IS APPROXIMATELY 4 POUNDS OF PAYLOAD FOR 1 POUND OF INERT WEIGHT.

IN THIS REGARD, WE WISH TO POINT OUT THAT THE AIR FORCE ROCKET PROPULSION LABORATORY (RPL) IS CURRENTLY SPONSORING ENGINE STUDIES WITH PRATT AND WHITNEY, AEROJET, AND ROCKETDYNE TO SUPPORT THE AIR FORCE'S ORBIT-TO-ORBIT SHUTTLE (OOS) STUDIES. THE RPL STUDIES WILL PROVIDE PARAMETRIC DATA FOR NEW HIGH PERFORMANCE LH₂/LO₂ ENGINES IN THE 8000-50,000 LB THRUST RANGE WITH A POINT DESIGN AT 25,000 LB THRUST. THESE STUDIES SHOULD BE CONSIDERED AS A SOURCE OF PROPULSION SYSTEM DATA FOR PHASE A TUG WORK AS WELL.

FINALLY, WE WISH TO POINT OUT THAT IF THE TUG MAIN ENGINE IS IN THE 10,000-15,000 LB THRUST RANGE, THERE IS THE POSSIBILITY OF COMMONALITY WITH THE SHUTTLE ORBITER OMS ENGINES. THUS IF THE TUG SIZE CALLS FOR A THRUST LEVEL IN THE RANGE OF SAY, 20,000-30,000 LBS, TWO OR MORE SMALL ENGINES SHOULD BE CONSIDERED AS AN ALTERNATIVE TO A SINGLE LARGE ENGINE. MINOR IMPROVEMENTS OF THE CURRENT RL-10 SHOULD BE INCLUDED FOR CONSIDERATION.

*SEE REFERENCE 8 FOR FURTHER COMMENTS.

SPACE SHUTTLE/TUG INTERFACE DATA

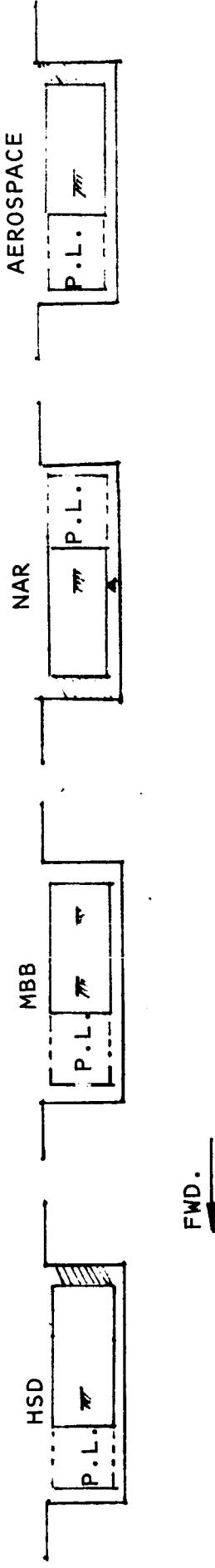
- DEFINED DATA
 - SHUTTLE PAYLOAD CAPABILITY
 - PAYLOAD BAY GEOMETRY
- UNDEFINED DATA
 - STRUCTURAL PROVISIONS FOR TUG SUPPORT
 - C.G. CONTROL
 - THERMAL ENVIRONMENT
 - DEPLOYMENT PROVISIONS
 - DOCKING PROVISIONS
 - FLUID INTERFACES
 - CABLING INTERFACES

SPACE SHUTTLE/TUG INTERFACE DATA

FOR THE PRE-PHASE A TUG STUDIES, THE SHUTTLE DATA PROVIDED WAS ONLY THE SHUTTLE PAYLOAD CAPABILITY (47K FOR THE ELD0 STUDIES AND 45K TO 80K FOR THE AMERICAN STUDIES) AND THE PAYLOAD BAY GEOMETRY (15 FT DIA X 60 FT LONG).

THESE DATA WERE ADEQUATE TO PROVIDE TUG SIZING FROM WHICH PRELIMINARY PAYLOAD CAPABILITY AND OTHER PARAMETRIC DATA COULD BE DERIVED, BUT MORE SPECIFIC SHUTTLE DATA MUST BE MADE AVAILABLE TO DEFINE THE TUG. DATA ON STRUCTURAL INTERFACES, CONSTRAINTS ON COMBINED C.G. LOCATIONS DURING EACH PHASE OF OPERATION, THE THERMAL ENVIRONMENT, DEPLOYMENT AND DOCKING PROVISIONS, AND THE FLUID AND ELECTRICAL INTERFACES ARE REQUIRED.

**STRUCTURAL/MECHANICAL INTERFACES
(TUG SUPPORT)**



- STRUCTURAL IMPACT ON SHUTTLE
 - LOCATION OF PRIMARY STRUCTURE
- POSITIONING OF TUG
 - INDEXING TO ALIGN SHUTTLE/TUG INTERFACE
 - INFLUENCE OF TUG C.G.
 - EFFECT OF INVERTED SUPPORT
- THERMAL ENVIRONMENT
 - SHUTTLE PAYLOAD BAY TEMPERATURE PROFILE

STRUCTURAL/MECHANICAL INTERFACES

ILLUSTRATED ARE THE DESIGN APPROACHES USED BY THE CONTRACTORS FOR SUPPORT OF THE TUG WITHIN THE SHUTTLE PAYLOAD BAY. AS SHOWN, EACH APPROACH IS SOMEWHAT DIFFERENT USING SUPPORT FROM THE SHUTTLE END BULKHEADS, ALONG THE SIDEWALLS, OR SOME COMBINATION OF EACH. THIS DIVERSITY OF APPROACHES ILLUSTRATES THE NECESSITY FOR FURTHER TUG DEFINITION.

A STRUCTURAL INTERFACE MUST BE ESTABLISHED BY EITHER THE SHUTTLE OR THE TUG. (SHUTTLE CONTRACTORS ARE IN THE PROCESS OF PREPARING PRELIMINARY INTERFACE DATA.)

ANGULAR INDEXING AND VERTICAL ALIGNMENT WILL BE REQUIRED TO EFFECT POSITIVE MATING OF THE SHUTTLE/TUG STRUCTURAL INTERFACE. NAR BRIEFLY DISCUSSED THIS AS A DESIGN CONDITION REQUIRING STUDY. CENTER OF GRAVITY LIMITS WHICH AFFECT THE REENTRY AND LANDING PHASE WERE CONSIDERED A PRIMARY DESIGN CONDITION BY BOEING. SUCH LIMITS REQUIRE PROPER ORIENTATION OF PAYLOADS FORE AND AFT AND MAY AFFECT PAYLOAD OR TUG DIMENSIONS. (MDAC'S PRELIMINARY INTERFACE DOCUMENT DEFINES THESE LIMITS.)

AS SHOWN, NAR SELECTED A SPACE SHUTTLE/TUG INTERFACE WHICH PLACES THE TUG IN AN INVERTED POSITION FOR LAUNCH (ENGINE-UP). THIS ARRANGEMENT MAY INTRODUCE ADDITIONAL DESIGN AND TEST REQUIREMENTS TO THE PROPELLANT SYSTEM FILL, DRAIN AND VENT SYSTEMS, SINCE DURING GROUND TESTING THE STAGE WOULD BE TESTED ENGINE DOWN.

SPACE SHUTTLE PAYLOAD BAY TEMPERATURES MUST BE CONSIDERED WITH A CRYOGENIC TUG. ANY TUG TEMPERATURE SENSITIVITY WOULD IMPACT THE TUG DESIGN. ONE SHUTTLE CONTRACTOR INDICATED AN UPPER LIMIT OF 250°F ON THE INTERIOR SURFACE OF THE PAYLOAD DOORS IF ALUMINUM SUBSTRUCTURE WAS USED. INSULATION OR CONDITIONING OF THE SHUTTLE PAYLOAD COMPARTMENT MAY BE REQUIRED, OR A PENALTY MAY BE IMPOSED ON THE TUG.

FLUID AND CABLING INTERFACES

FLUID -

- PROPELLANT FILL, DRAIN AND DUMP
 - THROUGH PAYLOAD BAY HATCH
OR
 - THROUGH AFT BULKHEAD TO ORBITER BASE FACE
- PROPELLANT VENT
 - OVERBOARD
OR
 - TO PAYLOAD BAY
- PROPELLANT TRANSFER (OMS)

CABLING -

- MONITORING, CHECKOUT, AND/OR COMMAND OF TUG SYSTEMS
- ELECTRICAL POWER?

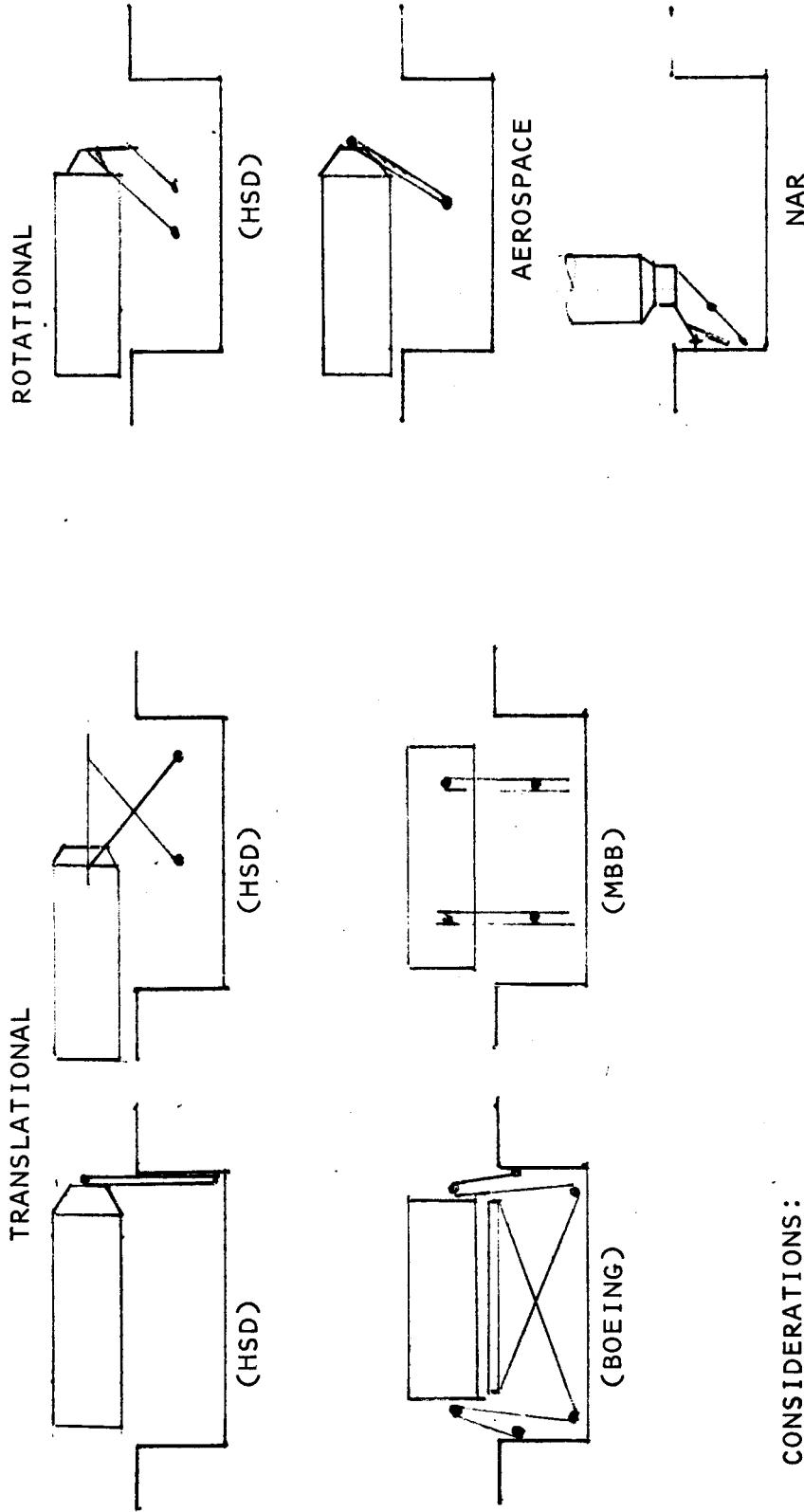
FLUID AND CABLING INTERFACES

FLUID AND CABLE INTERFACES WERE ONLY BRIEFLY DISCUSSED BY THE TUG CONTRACTORS AS FOLLOWS:

FLUID - FOR PROPELLANT FILL, DRAIN, AND POSSIBLY DUMP, HARDLINE INTERFACES WILL BE REQUIRED. THERE WERE TWO APPROACHES CONSIDERED DURING THE STUDIES NAMELY, (1) LINES FROM THE TUG INTERFACING AT OR PASSING THROUGH THE PAYLOAD BAY HATCH, AND (2) LINES FROM THE TUG PASSING THROUGH THE SHUTTLE AND EXITING AT THE ORBITER BASE FACE. PROPEL-LANT VENTING WAS CONSIDERED AS EITHER GOING OVERBOARD OR TO THE PAYLOAD BAY. (MDAC INTERFACE DOCUMENT PROPOSED A SCHEME FOR VENT-ING THROUGH THE PAYLOAD HATCH.) ANOTHER FLUID INTERFACE DISCUSSED BY NAR WAS OMS PROPELLANT TRANSFER.

CABLING - INTERFACES ARE REQUIRED FOR MONITORING, CHECKOUT, AND CONTROL OF TUG SYSTEMS AS WELL AS POSSIBLY ELECTRICAL POWER.

DEPLOYMENT CONCEPTS STUDIED



CONSIDERATIONS:

- VOLUME IMPACT - TUG SIZE & SHUTTLE ENVELOPE
- SYSTEM WEIGHT EFFECT ON TUG
- STRUCTURAL IMPACT ON TUG & SHUTTLE
- TUG / SHUTTLE INTERFACE SEPARATION

DEPLOYMENT CONCEPTS STUDIED

TUG DEPLOYMENT APPROACHES WERE PRELIMINARY CONCEPTUAL IDEAS. SHOWN HERE ARE SEVERAL OF THE CONCEPTS CONSIDERED, WHICH FALL INTO TWO CATEGORIES: TRANSLATIONAL OR ROTATIONAL.

SOME OF THE DESIGN PARAMETERS WHICH MUST BE CONSIDERED FOR ANY FUTURE STUDIES ARE:

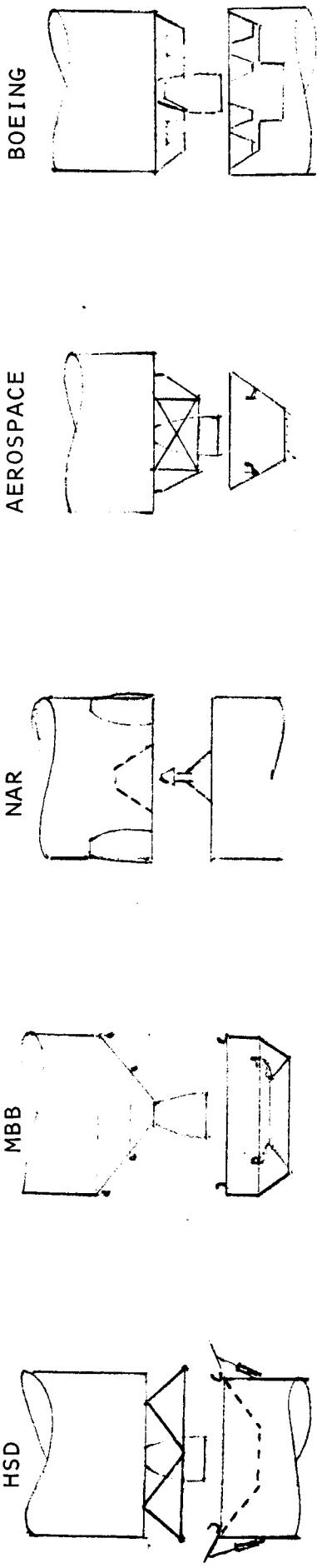
VOLUME IMPACT - WITHIN A CONSTRAINED ENVELOPE, VOLUME REQUIRED FOR THE DEPLOYMENT MECHANISM COULD REDUCE THE TUG SIZE. THE CONCEPTS SHOWN CONSUME VOLUME EITHER AT THE FRONT OR REAR BULKHEAD, ALONG THE SIDES, OR ON THE BOTTOM OF THE PAYLOAD BAY.

SYSTEM WEIGHT - ALTHOUGH THE DEPLOYMENT MECHANISM IS OPERATED IN ZERO 'G', IT MUST WITHSTAND LAUNCH AND REENTRY LOADS AND CAN THEREFORE BE A WEIGHT PENALTY CHARGED EITHER TO THE TUG OR SHUTTLE.

STRUCTURAL IMPACT - THE DEPLOYMENT MECHANISM SUPPORT WILL IMPACT ON BOTH THE SHUTTLE AND TUG STRUCTURE.

TUG/SHUTTLE INTERFACE SEPARATION - PLACEMENT OF VARIOUS TYPES OF UMBILICALS BETWEEN THE TUG & SHUTTLE AND METHODS OF SEPARATION MUST BE CONSIDERED.

DOCKING CONCEPTS



RING & FINGER

- TESTED (MENASCO) • CONCEPTUAL
- COMBINED DOCKING AND DEPLOYMENT CONCEPT

PROBE & DROGUE

- APOLLO • CONCEPTUAL
- CENTERLINE METHOD FOR MULTIPLE ENGINE CONFIGURATION

PROBE & DROGUE

- 110# 3% OF DRY WGT. • 44# 1% OF DRY WGT.
- 360# 3% OF DRY WGT. • NO SPECIFIC WGT. GIVEN
- 162# 3% OF DRY WGT.

DOCKING CONCEPTS

STUDIES FOR TUG DOCKING INCLUDED BOTH EXISTING DESIGNS AND CONTRACTOR CONCEPTUAL APPROACHES. ILLUSTRATED ARE THE METHODS SELECTED BY EACH CONTRACTOR.

HSD USED AN EXISTING DESIGN (THE RING AND FINGER CONCEPT) WHICH HAS BEEN BUILT AND TESTED BY MENASCO, AN AMERICAN COMPANY, BUT HAS NOT BEEN OPERATIONALLY USED. MBB'S CONCEPT IS A RING AND CAPTURE HOOK WHICH IS A CONCEPTUAL MODIFICATION OF THE MENASCO DESIGN. THIS APPROACH COULD BE USED AS A COMBINED DOCKING AND DEPLOYMENT DEVICE. NAR USED APOLLO PROBE AND DROGUE DEVICES LOCATED ON THE TUG CENTERLINE. AEROSPACE AND BOEING BOTH USED CONCEPTUAL PROBE AND DROGUE DESIGNS.

SOME SIGNIFICANT RESULTS

- 80-100K GROSS WT TUG (REUSABLE) REQUIRED FOR 10K TO GEOSYNCH SPACE BASED SYSTEM
- TWO SHUTTLE LAUNCHES WITH ON-ORBIT ASSEMBLY ABES REMOVED FROM SHUTTLE ORBITER + OMS SHARING WITH TUG AND/OR DOWN RANGE LANDING OR INFLIGHT REFUELING OF BOOSTER
- HIGH SENSITIVITY OF SINGLE REUSABLE STAGE FOR GEOSYNCHRONOUS MISSIONS
- OMS PROPELLANT SHARING IDENTIFIED AS POTENTIAL MAJOR FACTOR
- AVIONICS SYSTEM SIGNIFICANT FACTOR IN INERT WEIGHT
- MASS FRACTION DEGRADATION DIMINISHES BENEFITS OF STAGING
- EARLY BREAK EVEN ON COST OF REUSABLE VS. NEW EXPENDABLE TUG OR CONVENTIONAL LAUNCH VEHICLES FOR GEOSYNCHRONOUS MISSIONS - BUT SENSITIVE TO REUSABLE STAGE PERFORMANCE DOES NOT CONSIDER POSSIBLE IMPACT ON SHUTTLE VALID FOR SINGLE SHUTTLE LAUNCH
- LARGE OFFLOADED TUG (GEOSYNCH OR LUNAR) COMPETITIVE WITH SMALL TUG FOR LOW ORBIT SUPPORT
- PRELIMINARY WEIGHT, PERFORMANCE AND COST ESTIMATES
- PRELIMINARY CONFIGURATION AND SUBSYSTEM TRADEOFFS AND SELECTION
- PRELIMINARY ASSESSMENT OF PENALTIES FOR MODULARIZED VS INTEGRAL AVIONICS SPACE VS GROUND BASED
- SEVERAL APPROACHES TO ALL-PURPOSE TUG SYSTEM IDENTIFIED
BOEING
NAR
AEROSPACE
- POTENTIAL PERFORMANCE ADVANTAGE IDENTIFIED FOR AEROBRAKING TUG, BUT TECHNICAL ANALYSIS INADEQUATE

SOME SIGNIFICANT RESULTS

DESPITE A DIVERSITY OF APPROACHES, CONCEPTS, AND GROUND RULES IN THE PRE-PHASE A STUDIES, A NUMBER OF CONCLUSIONS AND ACCOMPLISHMENTS CAN BE IDENTIFIED FROM THE OVERALL EFFORT. SOME OF THE MORE SIGNIFICANT OF THESE FOLLOW.

A FULLY REUSABLE TUG WOULD HAVE TO WEIGH 80 TO 100 THOUSAND LBS, INCLUDING PAYLOAD, IN ORDER TO PLACE 10,000 LBS PAYLOAD IN GEOSYNCHRONOUS ORBIT AND RETURN EMPTY. THE PRESENT PHASE B SHUTTLE COULD ACCOMPLISH THIS IN A SINGLE LAUNCH IF THE ORBITER AIRBREATHING ENGINES ARE REMOVED, AND PROPELLANT SHARING (AS EXPLAINED BELOW) BETWEEN THE SHUTTLE ORBITAL MANEUVERING SYSTEM (OMS) AND THE TUG IS ADOPTED.* DOWN RANGE LANDING OR INFILIGHT REFUELING OF THE SHUTTLE BOOSTER MIGHT ALSO BE REQUIRED IF THE TUG WEIGHT IS AT THE UPPER END OF THE RANGE. IF THESE SHUTTLE PERFORMANCE OPTIONS ARE NOT INCORPORATED, THEN MULTIPLE SHUTTLE LAUNCHES AND EITHER SPACE BASING OR ON-ORBIT ASSEMBLY WOULD BE REQUIRED FOR THE 10,000 LB GEOSYNCHRONOUS ORBIT DELIVERY MISSION.

OMS PROPELLANT SHARING BETWEEN THE SHUTTLE ORBITER AND THE TUG HAS BEEN IDENTIFIED AS A POTENTIAL MAJOR FACTOR IN THE SHUTTLE/TUG PERFORMANCE. THE IDEA IS THAT THERE IS A CERTAIN AMOUNT OF CONTINGENCY PROPELLANT WHICH MUST BE ALLOTTED FOR A SHUTTLE ABORT TO ORBIT USING THE OMS ENGINES; THIS REQUIREMENT COULD BE MITIGATED IN ONE OF TWO WAYS. EITHER PROPELLANT COULD BE TRANSFERRED FROM THE TUG TO THE OMS IN THE EVENT OF SUCH AN ABORT, OR IF THE FLIGHT IS NOT ABORTED PROPELLANT COULD BE TRANSFERRED FROM THE OMS TO THE TUG ONCE IN ORBIT. EITHER METHOD WOULD PROVIDE APPROXIMATELY 25,000 LBS TUG PROPELLANT ABOVE THE BASELINE SHUTTLE CAPABILITY.

THE AVIONICS SYSTEM HAS BEEN IDENTIFIED AS A SIGNIFICANT FACTOR IN TUG INERT WEIGHT. THERE ARE MAJOR DIFFERENCES BETWEEN THE AVIONICS SYSTEMS WEIGHTS IN THE

*Presently defined shuttle capability with airbreathers removed is approaching 80,000 lbs due east payload. A 10K geosynchronous delivery mission might therefore be marginally within the capability of a single shuttle launch without additional performance options such as OMS propellant sharing.

AMERICAN AND EUROPEAN TUG STUDIES WHICH APPEAR TO BE DUE TO DIFFERENT LEVELS OF CAPABILITY AND MODULARITY.

THE STUDIES CONFIRM THAT THE PERFORMANCE CAPABILITY OF A SINGLE STAGE REUSABLE TUG FOR GEOSYNCHRONOUS MISSIONS IS EXTREMELY SENSITIVE TO INERT WEIGHT, ENGINE SPECIFIC IMPULSE, AND VELOCITY REQUIREMENTS; THE BASIC FEASIBILITY MUST STILL BE CONSIDERED UNCERTAIN, PARTICULARLY FOR SMALLER TUG SIZES. THE STUDIES ALSO SHOW THAT, FOR A GIVEN GROSS WEIGHT, THE BENEFITS OF STAGING AS COMPARED WITH A SINGLE STAGE SYSTEM ARE SIGNIFICANTLY DIMINISHED BECAUSE OF THE DEGRADATION OF MASS FRACTION WITH DECREASING STAGE WEIGHT. THUS, THE SINGLE VS TWO-STAGE QUESTION IS UNRESOLVED.

COST ANALYSES CONDUCTED AS PART OF THE PRE-PHASE A STUDIES TEND TO SUPPORT THE COST-EFFECTIVENESS OF A REUSABLE TUG. THE STUDIES GENERALLY SHOW AN EARLY BREAK-EVEN POINT FOR THE REUSABLE TUG AS COMPARED EITHER WITH A NEW EXPENDABLE TUG (USED IN CONJUNCTION WITH THE SPACE SHUTTLE), OR WITH THE CONTINUED USE OF THE CURRENT STABLE OF EXPENDABLE LAUNCH VEHICLES AND STAGES. THE BENEFITS OF PAYLOAD RETRIEVAL WOULD BE ADDITIONAL. HOWEVER, THERE ARE A NUMBER OF QUALIFICATIONS TO THESE CONCLUSIONS. FIRST OF ALL, THE COST EFFECTIVENESS OF A REUSABLE TUG APPEARS TO BE SENSITIVE TO REUSABLE STAGE PERFORMANCE. SECONDLY, THE COST EFFECTIVENESS OF A REUSABLE TUG WOULD BE DEGRADED SUBSTANTIALLY, PERHAPS NEGATED, IF MISSION REQUIREMENTS RESULT IN A NECESSITY FOR MULTIPLE SHUTTLE LAUNCHES FOR REUSABLE TUG MISSIONS VS A SINGLE SHUTTLE LAUNCH IF AN EXPENDABLE TUG WERE USED. THIS COULD WELL BE THE CASE FOR 10,000 LB PAYLOAD DELIVERY TO GEOSYNCHRONOUS ORBIT. FOR EXAMPLE. ALTERNATIVELY, THE REQUIREMENTS OF A REUSABLE TUG COULD NECESSITATE SHUTTLE PERFORMANCE IMPROVEMENTS (SUCH AS OMS PROPELLANT SHARING) WHICH WOULD ADD TO THE COST OF THE SHUTTLE PROGRAM.

SEVERAL OF THE STUDIES EXAMINED A RELATIVELY SMALL REUSABLE TUG WHICH WOULD BE SIZED FOR LOW EARTH ORBIT SUPPORT MISSIONS. EXPENDABLE OPTIONS SUCH AS DROP TANKS COULD BE

USED TO AUGMENT ITS PERFORMANCE FOR HIGH ENERGY MISSIONS SUCH AS GEOSYNCHRONOUS OR LUNAR. THE RESULTS INDICATE, HOWEVER, THAT THERE WOULD NOT BE ANY SUBSTANTIAL COST SAVINGS DUE TO USING A SMALL SUPPORT TUG RATHER THAN AN OFF-LOADED FULL-SIZE TUG FOR THE LOW EARTH ORBIT MISSIONS.

THE BOEING STUDY HAS IDENTIFIED AEROBRAKING AS A CONCEPT WHICH COULD IN PRINCIPLE SUBSTANTIALLY REDUCE THE WEIGHT AND COST OF A REUSABLE TUG. HOWEVER, THE TECHNICAL ANALYSIS TO DATE IS NOT OF ADEQUATE DEPTH TO ESTABLISH THE AEROBRAKING CONCEPT AS A FEASIBLE OR REALISTIC CONTENDER FOR IMPLEMENTATION AT THIS TIME.

GENERAL ACCOMPLISHMENTS OF THE PRE-PHASE A STUDIES INCLUDE PRELIMINARY WEIGHT, PERFORMANCE, AND COST ESTIMATES; PRELIMINARY TRADEOFFS AND SELECTIONS OF CONFIGURATIONS AND SUBSYSTEMS; PRELIMINARY ASSESSMENT OF PENALTIES FOR SPACE VS. GROUND BASING, DEGREE OF AUTONOMY, AND MODULAR VS INTEGRATED AVIONICS; AND IDENTIFICATION OF SEVERAL APPROACHES TO AN ALL-PURPOSE TUG SYSTEM, I.E. ONE CAPABLE OF SUPPORTING A FULL SPECTRUM OF MANNED AND UNMANNED MISSIONS.

TECHNICAL GUIDELINE RECOMMENDATIONS

- MORE THAN ONE LEVEL OF SHUTTLE PAYLOAD CAPABILITY
- INCLUDE IMPACT OF SHUTTLE OMS PROPELLANT SHARING
- ONE AND TWO STAGE FULLY REUSABLE TUGS
 - DROP THE 1 1/2 STAGE CONCEPT
- EXPENDABLE OPTIONS FOR PLANETARY OR LARGE PAYLOAD GEOSYNCHRONOUS MISSIONS
 - INCLUDE KICK STAGES
- INTEGRAL AVIONICS
- IMPACT OF ADVANCED TECHNOLOGY SUBSYSTEMS
- SHUTTLE/TUG INTERFACE SPECIFICATIONS NEEDED
- PROGRAM MODEL(S) SIMILAR TO THAT FOR SHUTTLE PROGRAM
 - INCLUDE PAYLOAD DIMENSION EFFECTS
- ANALYZE, RATHER THAN ASSUME, SYSTEM REUSE CAPABILITY
- CONSIDER ENGINE DATA FROM AF STUDIES

TECHNICAL GUIDELINE RECOMMENDATIONS

SINCE A NUMBER OF DESIGN AND OPERATIONAL OPTIONS MAY OR MAY NOT EVENTUALLY BE INCORPORATED INTO THE SPACE SHUTTLE PROGRAM, THE DELIVERY (AND RETURN) CAPABILITY OF THE SHUTTLE MUST BE CONSIDERED UNCERTAIN AT THIS TIME. IT WOULD BE WISE, THEREFORE, TO INCORPORATE MORE THAN ONE LEVEL OF SHUTTLE CAPABILITY INTO THE PHASE A TUG STUDIES RATHER THAN FIXING ON A SINGLE SPECIFICATION. THIS MIGHT BE DONE EITHER BY TAKING PARAMETRIC VARIATIONS ABOUT A BASELINE CASE, OR BY CARRYING OUT TUG POINT DESIGNS FOR TWO OR MORE LEVELS OF SHUTTLE PERFORMANCE.

THE CONCEPT OF OMS PROPELLANT SHARING BETWEEN THE TUG AND SHUTTLE ORBITER FOR SHUTTLE ABORT-TO-ORBIT CONTINGENCIES SHOULD SPECIFICALLY BE INCLUDED FOR FUTURE EVALUATION. THIS SHOULD BE STUDIED WITH REGARD TO ITS IMPACT ON TUG DESIGN AND PERFORMANCE.

SINCE THE QUESTION OF SINGLE VS TWO REUSABLE STAGES HAS NOT BEEN RESOLVED, STUDY EFFORT SHOULD CONTINUE ON BOTH. HOWEVER, IT IS FELT THAT THE 1 1/2 STAGE CONCEPT (SINGLE REUSABLE STAGE PLUS EXPENDABLE DROP TANKS) SHOULD BE DROPPED FROM FURTHER CONSIDERATION AS A BASELINE TUG DESIGN. THE USE OF DROP TANKS WAS PRIMARILY OF INTEREST AS A WAY OF AUGMENTING THE PERFORMANCE OF A SMALL REUSABLE SUPPORT TUG FOR GEOSYNCHRONOUS OR OTHER HIGH ENERGY MISSIONS. HOWEVER, THE SUPPORT TYPE MISSIONS CAN BE CARRIED OUT NEARLY AS EFFICIENTLY WITH A FULL-SIZED (I.E., SIZED FOR GEOSYNCHRONOUS) REUSABLE TUG, OPERATED OFFLOADED, AND THE USE OF DROP TANKS FOR THE GEOSYNCHRONOUS MISSIONS DOES NOT APPEAR TO OFFER ANY SIGNIFICANT PERFORMANCE ADVANTAGE OVER A FULLY REUSABLE TUG. THEREFORE THE 1 1/2 STAGE CONCEPT IS NOT LIKELY TO BE COST EFFECTIVE. HOWEVER, THIS DOES NOT PRECLUDE CONSIDERATION OF DROP TANKS FOR OCCASIONALLY AUGMENTING THE PAYLOAD DELIVERY CAPABILITY OF A FULLY REUSABLE TUG FOR MISSIONS REQUIRING GREATER THAN THE BASELINE GEOSYNCHRONOUS MISSION CAPABILITY.

OTHER EXPENDABLE OPTIONS FOR OCCASIONAL DELIVERY OF LARGE GEOSYNCHRONOUS PAYLOADS, HIGH ENERGY PLANETARY MISSIONS, ETC., SHOULD ALSO CONTINUE TO BE EXPLORED. IN PARTICULAR, THE USE OF SOLID PROPELLANT KICK STAGES APPEARS TO BE A COST-EFFECTIVE AND STRAIGHTFORWARD WAY OF AUGMENTING PAYLOAD DELIVERY CAPABILITY.

THE ONGOING STUDIES SHOULD INCORPORATE INTEGRAL AVIONICS IN THEIR DESIGNS RATHER THAN PROVIDING A SEPARATE AVIONICS MODULE. IT APPEARS THAT A SIGNIFICANT WEIGHT PENALTY WOULD BE INCURRED WITH SUCH MODULARITY, AND THE ONLY ADVANTAGES OF MODULAR AVIONICS WOULD BE FLEXIBILITY FOR MANNED MISSIONS WHICH MIGHT OCCUR SUBSTANTIALLY LATER THAN THE INITIAL OPERATION OF THE TUG. THE DEGREE OF TUG AUTONOMY TO BE PROVIDED BY THE AVIONICS SYSTEMS SHOULD BE CAREFULLY SPECIFIED AND THE WEIGHT PENALTIES ASSOCIATED WITH INCREASING DEGREES OF AUTONOMY AND WITH SPACE VS GROUND BASING SHOULD BE SPECIFICALLY IDENTIFIED.

THE IMPACT OF ADVANCED TECHNOLOGY SUBSYSTEMS ON THE PERFORMANCE AND OPERATION OF THE TUG SHOULD BE CONSIDERED, PARTICULARLY IN EVOLUTIONARY OR FOLLOW-ON VERSIONS OF THE TUG.

A NEED TO DEFINE THE SHUTTLE/TUG INTERFACES HAS BEEN CLEARLY ESTABLISHED. INFORMATION AND SPECIFICATIONS BEING DEVELOPED IN THE PHASE B SHUTTLE STUDIES AND IN THE PREPARATION FOR PHASE C SHOULD BE APPLIED.

COST & PROGRAM ANALYSES IN THE PHASE A STUDIES SHOULD INCORPORATE A TRAFFIC MODEL OR MODELS SIMILAR TO THAT BEING USED IN SHUTTLE ECONOMICS STUDIES. THE EFFECT AND CONSTRAINTS OF PAYLOAD DIMENSIONS AS WELL AS WEIGHTS SHOULD BE INCLUDED, PARTICULARLY FOR THE PURPOSE OF COMPARING ALTERNATE TUG CONCEPTS.

IN THE PRE-PHASE A STUDIES, ARBITRARY ASSUMPTIONS WERE MADE WITH REGARD TO THE NUMBER OF REUSES OF EACH TUG. IT WOULD BE APPROPRIATE IN PHASE A TO INSTEAD ANALYZE

REUSE CAPABILITY, E.G. TO STUDY THE REQUIREMENTS IMPOSED ON EACH SUBSYSTEM BY EXTENDED LIFETIME AND VARYING DEGREES OF REUSE OR REFURBISHMENT.

THE DATA BEING GENERATED IN THE AIR FORCE RPL-SPONSORED OOS ENGINE STUDIES SHOULD BE INCLUDED AS PART OF THE REFERENCE DATA BASE FOR THE PHASE A STUDIES.

RECOMMENDATIONS FOR ADDITIONAL STUDIES

- φB SHUTTLE – SPECIAL TASK ON IMPACT OF OMS PROPELLANT SHARING
- ECONOMIC BENEFITS OF PAYLOAD RETRIEVAL
- AEROBRAKING STUDIES

DESIGN AND CONFIGURATION

TECHNOLOGY EVALUATION

MATERIALS

GUIDANCE, NAVIGATION & CONTROL

- ON ORBIT OPERATIONS & SYSTEMS

RENDEZVOUS & DOCK WITH NON-COOPERATIVE SATELLITES

FUELING

RECOMMENDATIONS FOR ADDITIONAL STUDIES

BECAUSE OF THE POTENTIAL SIGNIFICANCE OF THE OMS PROPELLANT SHARING CONCEPT FOR THE TUG, A SPECIAL STUDY IS RECOMMENDED TO ASSESS THE ENGINEERING IMPACT OF OMS PROPELLANT SHARING ON THE DESIGN OF THE PHASE B SPACE SHUTTLE. A BETTER UNDERSTANDING IS NEEDED OF THE ADDED COMPLEXITIES BEFORE THE NET VALUE OF THE CONCEPT CAN BE ASSESSED.

THE ECONOMIC BENEFITS OF PAYLOAD RETRIEVAL MAY BE A KEY FACTOR IN COMPARING A REUSABLE TUG WITH CURRENT EXPENDABLE STAGES SUCH AS CENTAUR OR AGENA. A SPECIAL STUDY IS THEREFORE RECOMMENDED IN THAT AREA AS WELL.

THE TUG AEROBRAKING CONCEPT NEEDS MORE DEPTH OF STUDY TO DEFINE TECHNOLOGICAL REQUIREMENTS OR INNOVATIONS ASSOCIATED WITH IT. A RECENT BELLCOMM STUDY* PRESENTS A PRELIMINARY ASSESSMENT OF ENTRY CORRIDOR REQUIREMENTS AND MATERIALS REQUIREMENTS FOR PASSIVE THERMAL PROTECTION DURING ENTRY AT LOW ANGLES OF ATTACK. HOWEVER, THERE IS PRESENTLY LITTLE OR NO INFORMATION AVAILABLE ON DESIGN AND CONFIGURATION ALTERNATIVES AND TRADEOFFS, AND STUDY IN THIS AREA WOULD BE HELPFUL. SUPPORTING TECHNOLOGY STUDIES OF ACTIVE COOLING CONCEPTS AND ADVANCED GUIDANCE, NAVIGATION AND CONTROL SYSTEMS ARE ALSO SUGGESTED.

STUDIES OF ON ORBIT TUG OPERATIONS, SUCH AS REFUELING IN SPACE AND RETRIEVAL OF NON-COOPERATIVE SATELLITES, WOULD BE USEFUL IN CONCEPTUALIZING ADJUNCT SYSTEMS.

*MEMO BY R. N. KOSTOFF, IN PREPARATION.



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Case 105-4

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